SITE SUITABILITY ANALYSIS OF MANGALURU CITY'S SOLID WASTE DISPOSAL THROUGH GEOSPATIAL TECHNOLOGIES

THESIS SUBMITTED TO THE MANGALORE UNIVERSITY FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN GEOGRAPHY

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CERTIFICATE

This is to certify that the thesis entitled **"SITE SUITABILITY ANALYSIS OF MANGALURU CITY'S SOLID WASTE DISPOSAL THROUGH GEOSPATIAL TECHNOLOGIES".** submitted by **Mr. SOMASHEKHARA** for the award of the degree of Doctor of Philosophy in Geography, is record of bonafide research work done by him during the year 2019-2024 in the Department of Geography, Mangalore University, Mangalagangothri, under my guidance and supervision. I considered that the thesis has reached the standards and fulfilling the requirement of the rules and regulation relating to the nature of the degree. The thesis has not formed the basis fully (or) partially for the award of any degree, diploma, or other similar titles to any other university or institution.

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DECLARATION

I hereby declare that the thesis entitled **"SITE SUITABILITY ANALYSIS OF MANGALURU CITY'S SOLID WASTE DISPOSAL THROUGH GEOSPATIAL TECHNOLOGIES"** submitted for the award of the Degree of the Doctor of Philosophy of Mangalore University is my original work and the thesis has not formed the basis for the award of any degree, diploma or fellowship of similar other titles of any other University or Institution.

Place: Signature of the Research Scholar

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INTRODUCTION

In recent years, rapid urbanization and population growth have led to an unprecedented increase in the generation of solid waste across the globe. As urban areas expand, so does the need for effective and sustainable waste management strategies to maintain the environmental quality and overall liability of cities. Mangaluru city, a vibrant coastal city in the southern state of Karnataka, India, is no exception to this challenge. The city's escalating population and economic development have resulted in a surge in solid waste production, necessitating the development of innovative and efficient methods for waste disposal and management.

This research addresses the critical issue of solid waste management in Mangaluru city by harnessing the power of geospatial technologies. Geospatial technologies encompass a diverse set of tools and techniques, including Geographic Information Systems (GIS), remote sensing, and Analytical hierarchy process (AHP), which enable the collection, analysis, and visualization of spatial data. The importance of efficient waste management cannot be overstated, as improper disposal practices can lead to a host of environmental and public health problems. Study area, with its unique geographical and environmental characteristics, presents a compelling case study for the application of geospatial technologies in addressing this challenge. The city's proximity to the Arabian Sea, its diverse topography, and the presence of ecologically sensitive areas make it imperative to adopt a systematic and data-driven approach to solid waste disposal site selection.

One of the primary goals of this research is to identify suitable locations Outside Mangaluru for the establishment of solid waste disposal sites. Traditionally, site selection has often relied on ad-hoc decision-making processes that may not consider the long-term sustainability and environmental impact of these sites. Geospatial technologies offer a more strong and scientific approach by allowing for the integration of multiple spatial data layers, such as, Physiographic, hydrologic and anthropogenic, to evaluate potential sites systematically. This research aims to explore the environmental implications of solid waste disposal in Mangaluru, with a particular focus on the potential impacts on water quality, soil health, and air quality. By conducting a comprehensive site suitability analysis, we can assess the risks associated with different disposal locations and develop strategies to mitigate any adverse effects on the environment.

Objectives:

The objectives of the research are as follows:

- To know the current scenario of solid waste management of Mangaluru city.

- To understand land use and land cover of study area.
- To analyse the physiographic and anthropogenic factors to demarcate the suitable dumpsite.
- To understand the hydrological nature of the study area, and
- To suggest suitable site for solid waste disposal by applying MCDMS and AHP.

METHODOLOGY

The methodology consists of the data collection, data processing and analysis. The present study requires data from both spatial and non-spatial types. The spatial data mainly consists of satellite imageries, Google earth imageries, SRTM DEM, Sentinel 2A images, GSI Bhukosh geomorphology and Geology, and transport networks etc. The non-spatial data such as census data from Census of India, NBSS and LUP soil map, Rainfall data, Groundwater data and other relevant government publications, reports etc. which are later converted into spatial data for the analysis purpose. The study was conducted using a wide range of software and techniques such as ArcGIS 10.8.2, Google Earth Pro, ENVI, Microsoft Excel, AHP, Weighted overlay analysis and Kappa statistics confusion matrix, Ground truth verification etc.

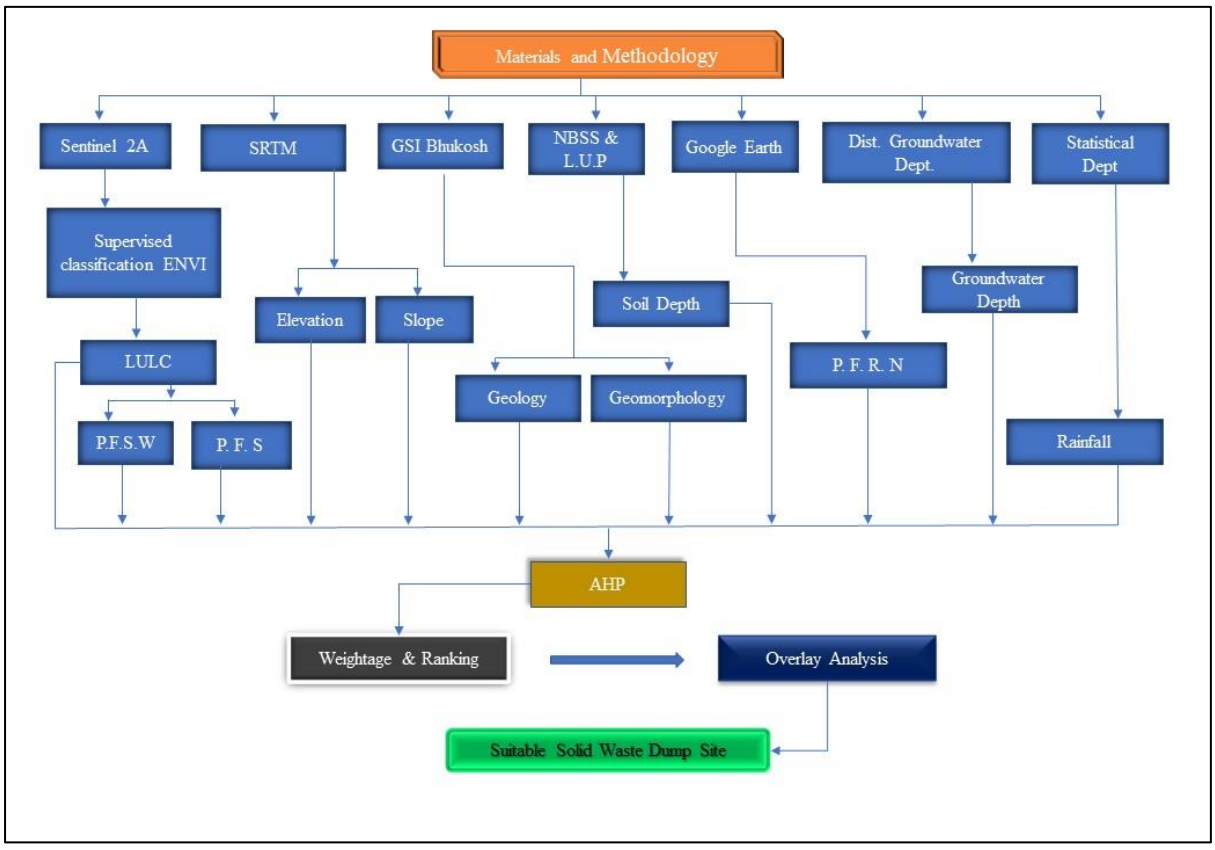

Fig. No.1: Methodology

The analysis of the study can be generally put under four sections as:

1. Data collection.

2. Criteria layer generated.
3. Application of analytical hierarchy process (AHP).
4. Result validation by ground truth verification.

ORGANIZATION OF THE CHAPTERS

The thesis is organised into 8 main chapters and can be broadly divided into two sections. The first part consisting of chapters 1 to chapter 3 deals with the introductory aspects of the study including background, concepts, literature review and the location of the study. The second part covers chapter 4 to chapter 8 deliberates upon the primary objectives of the study comprehensively. The main chapters (chapters 4 to 7) have been designed to comprehensively address each above-mentioned research objective by constructing a methodological framework and analysis to fit the data and finally to derive the results. Lastly, chapter 9 discusses the conclusion.

CHAPTER 1: INTRODUCTION

The chapter discusses the escalating concern of solid waste management at global, regional, and local levels. Factors such as population growth, urbanization, industrialization, and improved living standards have led to increased waste production, making it a complex challenge. Urban areas generate tons of waste daily from various sources like households, hospitals, industries, and offices, posing environmental and health risks. Landfill disposal remains the most common method, but it has its environmental consequences, including leachate contamination and greenhouse gas emissions. The chapter also outlines various types of solid waste, including domestic waste, waste from homes or buildings, commercial waste, institutional waste, garbage, rubbish, ashes, bulky waste, street waste, animal mortality, construction and demolition waste, industrial waste, hazardous waste, sewage waste, and hospital/biomedical waste. It highlights the need for proper classification and management of these waste types.

Furthermore, the chapter describes the modular components of municipal solid waste management, including waste generation, source sorting and processing, collection, sorting, processing and transformation, transport and transfer, and disposal methods like open dumping, landfilling, incineration, composting, biogas production, and gasification/pyrolysis. The hierarchy of municipal solid waste management prioritizes source reduction, reuse, recycling, waste processing with resource recovery, waste transformation, and landfilling in that order.

Poor waste management can lead to various consequences such as health risks, strong odours, fires, soil contamination, atmospheric pollution, climate change, and water pollution. The role of NGOs in solid waste management is highlighted, as they engage in activities such as organizing waste pickers, conducting awareness programs, addressing public grievances, and collaborating with municipal authorities. The chapter also provides guidelines from the Central Pollution Control Board (CPCB) for locating dump sites with minimum siting distances from sensitive areas like rivers, lakes, habitation, and road networks, also the chapter presents literature review covering the major objectives of the current study. The literature review is organized according to the order of the objectives stated in the study. The review has been done covering the relevant topics such as LULC changes, solid waste site suitability through Geospatial technologies such as ArcGIS, remote sensing and Analytical hierarchy process (AHP), etc. The literature review provides a validation of the research objectives, research question and methodology through literature gathered from the core academic discussions covering regional, national, and global scale in a definite chronology.

CHAPTER 2: STUDY AREA

It provides an overview of the study area. Besides, the chapter includes deliberations on the geographical location, administrative divisions, Slope, Elevation, Geomorphology, Geology, climatic settings, demography, economy, transportation, health sector, etc. Fig. no. 1. shows the Study area.

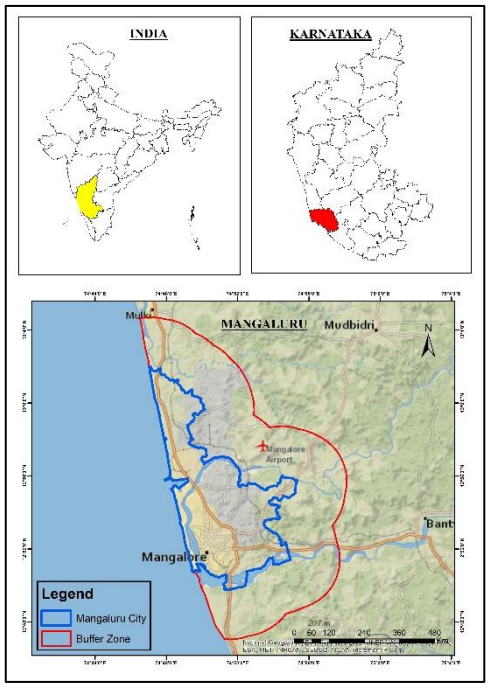

Fig. No.2: Study area

CHAPTER 3: AN OVERVIEW OF SOLID WASTE IN MANGALURU CITY

The chapter provides an overview of solid waste management in Mangaluru City. It emphasizes the challenges posed by rapid urbanization, which strains municipal infrastructure and public health. It also compares international waste generation trends, with developed

countries producing more waste per capita due to higher consumption levels. In contrast, developing nations generate less waste per capita, but a significant portion is organic. In India, biodegradable waste dominates municipal solid waste, with a per capita generation rate of 0.2 to 0.6 kilograms per day. The chapter further delves into the specific scenario in Karnataka, where eleven municipal corporations generate significant waste, with the majority originating from residential and market areas. The solid waste management in Mangaluru is discussed under various heads, including primary collection, street sweeping, secondary waste collection and transportation, informal and formal private sector involvement, and the role of NGOs and CBOs.

Additionally, Ward-wise aspects of Mangaluru City Corporation are presented, detailing residential and commercial areas, populations, and housing statistics. Tables illustrate solid waste collection data from 2015 to 2022, showing the quantities collected in North and South zones each month. Overall, Chapter IV provides a comprehensive understanding of the solid waste situation in Mangaluru, emphasizing the challenges faced and the various aspects of waste management within the city.

CHAPTER 4: PHYSIOGRAPHIC AND ANTHROPOGENIC FACTORS FOR THE ANALYSIS OF SOLID WASTE SITE SUITABILITY

This chapter focuses on assessing the suitability of solid waste disposal sites based on physiographic and anthropogenic factors. Physiographic factors, such as topography, geology, and soil characteristics, play a crucial role in determining a suitable waste disposal location. Steeper slopes, porous bedrock, and poor drainage can pose challenges, while flat, stable terrain with low-permeability soils is preferred. The study collected data on elevation, slope, geomorphology, geology, and soil depth to evaluate these physiographic factors (Fig. no. 3 & 4). It found that moderate slopes and moderate elevation areas were suitable for waste disposal, with low-permeability geology like granite gneiss and laterite being preferable.

Anthropogenic factors, which encompass LULC and transportation infrastructure, were also considered. Areas zoned for residential or commercial use were deemed less suitable, and proximity to road networks was assessed to prevent odour and pollutant dispersion. The study used satellite imagery and GIS analysis to determine LULC and proximity to roads and settlements (Fig. no. 5). Overall, the chapter aims to provide a comprehensive analysis of site suitability for solid waste disposal, considering both natural and human-related factors.

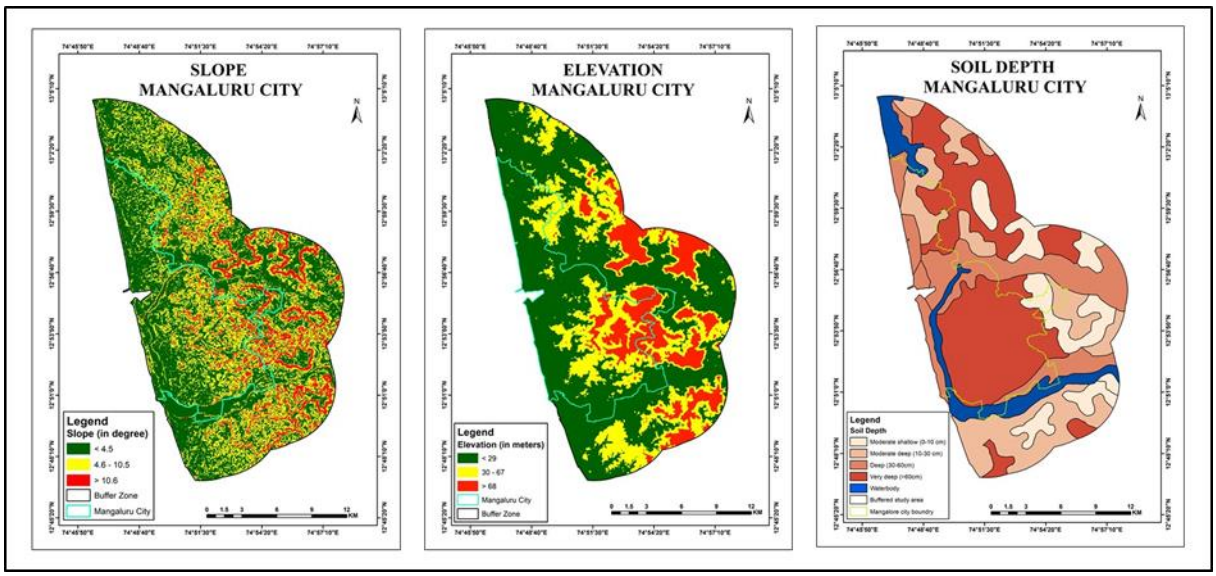

Fig. No.3: Slope, Elevation and Soil depth.

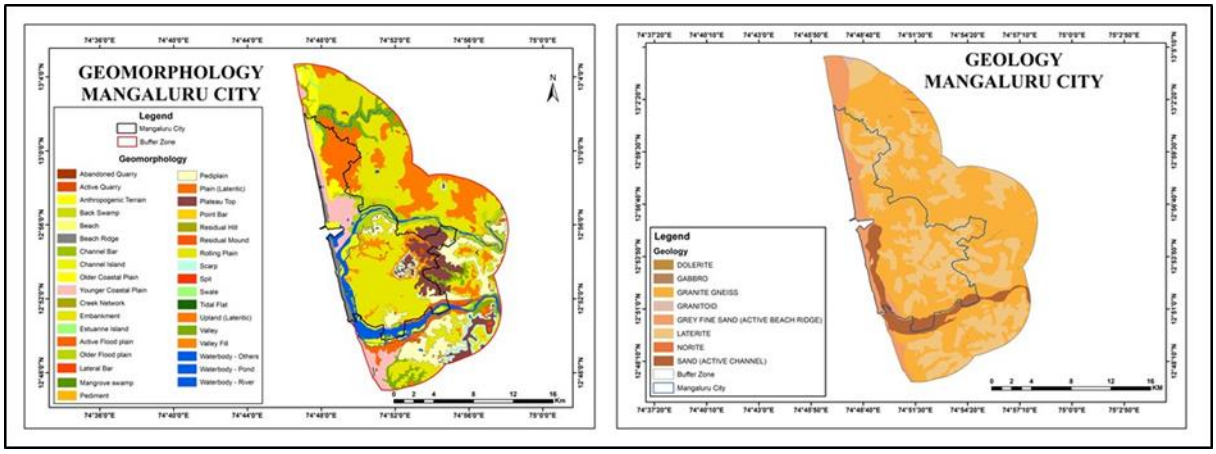

Fig. No.4: Geomorphology and Geology.

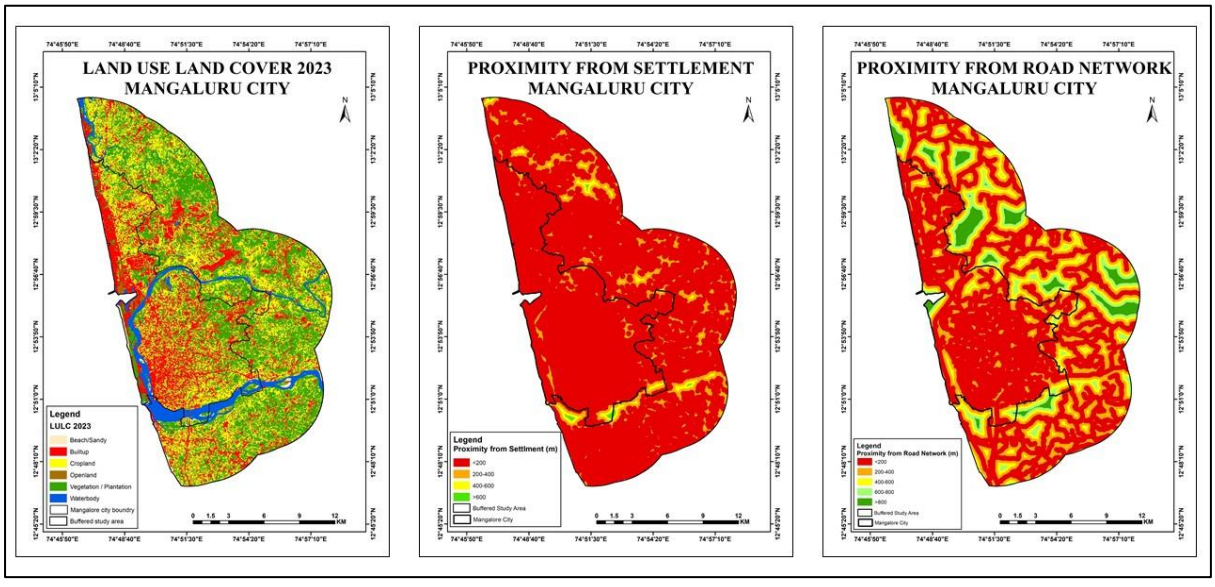

Fig. No.5: LULC, Proximity from settlement and Proximity from transport network

Table. no. 1 Accuracy Assessment, Confusion Matrix of LULC 2023

Class	A	B	C	D	E	F	Total	Users Accuracy	Kappa statistics
A	48	0	0	0	0	2	50	0.96	0
B	0	44	0	5	0	1	50	0.88	0
C	0	5	42	1	2	0	50	0.84	0
D	0	2	0	47	0	1	50	0.94	0
E	0	0	2	0	48	0	50	0.96	0
F	0	0	0	1	0	49	50	0.98	0
Total	48	51	44	54	50	53	300	0	0
Producer's Accuracy	1	0.86	1.0	0.9	1.0	0.9	0.0	**0.93**	0
Kappa statistics	0	0	0	0	0	0	0	0	**0.91**

A= Beach, B= Built-up, C=Cropland, D= Open land, E= Vegetation, F= Waterbody.

The findings are crucial for responsible waste management and environmental protection, aligning with CPCB guidelines and regulations.

CHAPTER 5: HYDROLOGICAL NATURE OF MANGALURU CITY

Chapter six of the work focuses on the hydrological nature of Mangaluru City in the context of solid waste disposal site suitability analysis. It emphasizes the importance of considering hydrological factors when determining the suitability of locations for waste dumps, given the increasing significance of waste management. The chapter discusses three key hydrological factors:

1. Groundwater Depth: The depth of groundwater is vital, as shallow groundwater can risk contamination from leachate produced by waste dumps. The study area's groundwater depth varies between 3.92-41.8 meters, with shallower depths in the northern part, making it unsuitable for waste disposal.
2. Rainfall: Rainfall patterns affect surface runoff, which can transport pollutants from waste dumps into water bodies. The study identifies rainfall zones, with higher rainfall areas deemed unsuitable for waste disposal due to increased contamination risks.
3. Proximity to Surface Water: The proximity of waste dumps to surface water bodies like rivers and lakes is critical to prevent contamination. The study classifies areas based on distance from surface water, with locations <200m considered unsuitable for waste dumps (Fig. no.6).

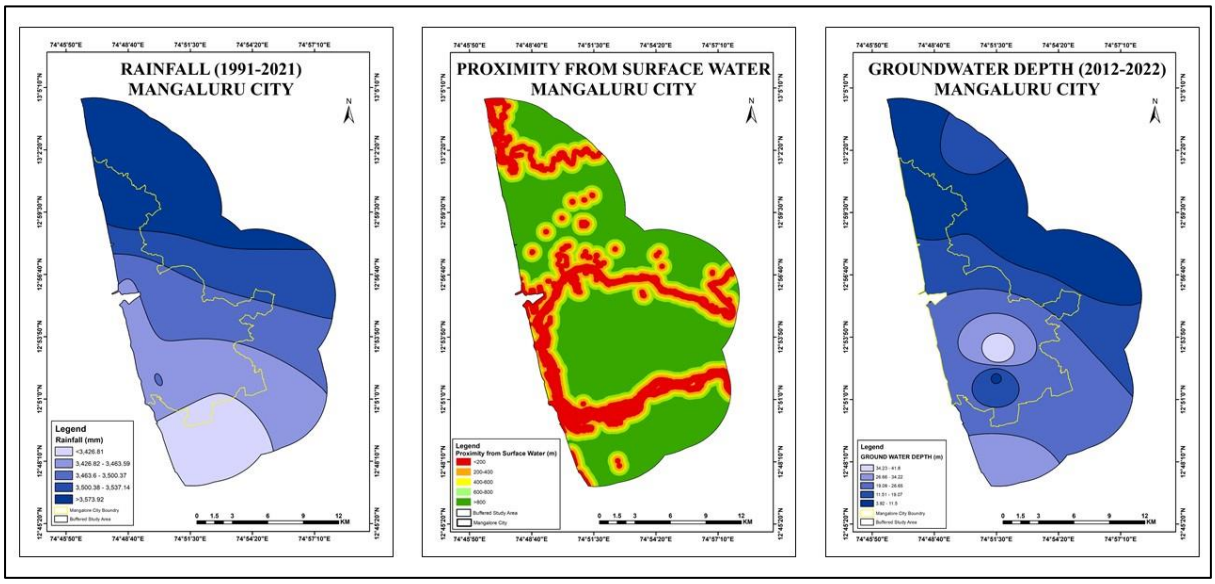

Fig. No.6: Rainfall, Proximity from surface water and Groundwater depth

The research employs data from various sources and GIS techniques to map and analyze these factors. It concludes that sites with deeper groundwater, lower rainfall, and greater distance from surface water are more suitable for waste disposal, emphasizing the importance of environmentally responsible waste management practices to protect water resources and public health.

CHAPTER 6: SITE SUITABILITY ASSESSMENT OF MANGALURU CITY

This chapter focuses on the site suitability assessment of Mangaluru City for solid waste disposal, recognizing the critical importance of proper waste management in urban areas. The increasing population, urban expansion, and the need for waste disposal in an environmentally responsible manner are the key drivers behind this assessment. The Analytical Hierarchy Process (AHP) was employed as a decision-making methodology (Table. no. 2) to evaluate 11 important factors for selecting an appropriate waste dump site (Table no.3). These factors include proximity to settlement areas, road networks, surface water bodies, groundwater depth, soil depth, land use and land cover (LULC), rainfall, elevation, slope, geology, and geomorphology.

Intensity of importance	Definition	Explanation
1	Equal importance	Two attributes contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	Activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of tile highest possible order of affirmation
2,4,6& 8	Intermediate values between the two adjacent judgments	When compromise is needed

Table no. 2 Scale of absolute numbers for pairwise comparisons

Formula to calculate Analytical hierarchy process (AHP).

Testing the consistency of the judgment matrix should be done by calculating the consistency index (CI), which is defined as

$$CI = \frac{\lambda \max - n}{n - 1}$$

The "CI" is defined as the consistency index (CI), where "λmax" represents the largest or principal eigenvalue of the matrix, and "n" denotes the order of the matrix. The "CR" coefficients are also computed in accordance with Saaty' s methodology. It is crucial for the "CR" coefficients to be less than 0.1, indicating the overall consistency of the pairwise comparison matrix.

"CR" is defined as

$$CI = \frac{CI}{RI}$$

Here, "RI" is the average of the resulting consistency index depending on the matrix. In this research, RI_{11} = 1.51 because of using eleven criteria.

Table no.3 Pair-wise comparison matrix

Pair-wise Comparison Matrix

Factors	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**CW**
A	1	1	3	1	1	3	0	0	0	1	0	**0.0303**
B	1	1	3	1	3	3	0	0	0	1	0	**0.0182**
C	1/3	0	1	0	3	5	0	0	0	0	0	**0.0182**
D	3	3	3	1	5	5	1	1	1	1	0	**0.0182**
E	1/3	1/3	1/3	1/5	1	3	0	0	0	0	0	**0.0182**
F	1/3	1/3	1/5	1/5	1/3	1	0	0	0	0	0	**0.0182**
G	5	4	5	1	5	5	1	1	0	1	1	**0.0909**
H	5	5	5	1	5	5	1	1	0	5	1	**0.0909**
I	1	1/2	1/3	1/3	1	1/3	1/5	1/5	1	0	3	**0.2727**
J	1	1	3	1	5	5	1	1/5	3	1	0	**0.0130**
K	3	5	5	5	5	5	1	1	1/3	7	1	**0.0909**
Sum	**21.00**	**21.50**	**28.87**	**11.93**	**34.33**	**40.33**	**6.25**	**5.40**	**7.13**	**18.07**	**7.48**	**1**

A=Slope, B=Groundwater, C=Rainfall, D=Geology, E=elevation, F=Geomorphology, G=LULC, H=Settlement, I=Soil depth, J=transportation, K=Surface water, CW-Criteria weight.

Table. no.4 Calculating Consistency index

Factors	A	B	C	D	E	F	G	H	I	J	K	Sum	CW (%)
A	0.05	0.05	0.10	0.08	0.03	0.07	0.03	0.04	0.03	0.06	0.04	0.58	5
B	0.05	0.05	0.10	0.08	0.09	0.07	0.04	0.04	0.03	0.06	0.03	0.63	6
C	0.02	0.02	0.03	0.02	0.09	0.12	0.03	0.04	0.05	0.02	0.03	0.46	4
D	0.14	0.14	0.10	0.08	0.15	0.12	0.16	0.19	0.14	0.06	0.03	1.31	12
E	0.02	0.02	0.01	0.02	0.03	0.07	0.03	0.04	0.03	0.02	0.03	0.31	3
F	0.02	0.02	0.01	0.02	0.01	0.02	0.03	0.04	0.03	0.01	0.03	0.22	2
G	0.24	0.19	0.17	0.08	0.15	0.12	0.16	0.19	0.05	0.06	0.13	1.53	14
H	0.24	0.23	0.17	0.08	0.15	0.12	0.16	0.19	0.05	0.28	0.13	1.80	16
I	0.05	0.02	0.01	0.03	0.03	0.01	0.03	0.04	0.14	0.01	0.40	0.77	7
J	0.05	0.05	0.10	0.08	0.15	0.12	0.16	0.04	0.42	0.06	0.02	1.24	11
K	0.14	0.23	0.17	0.42	0.15	0.12	0.16	0.19	0.05	0.39	0.13	2.15	20
												11	100

A=Slope, B=Groundwater, C=Rainfall, D=Geology, E=elevation, F=Geomorphology, G=LULC, H=Settlement, I=Soil depth, J=transportation, K=Surface water CW-Criteria weight.

Each factor was assigned weights and ranks based on pairwise comparisons (Table.no. 5), and the suitability analysis was conducted, resulting in a suitability map divided into suitable and unsuitable sites (Fig. no.7). The AHP process emphasized the importance of factors like proximity to surface water, settlement areas, and road networks, while giving less

Factors	Class	Rank	Weight (AHP)
Slope	<4.5	3	0.06
	4.6-10.5	3	
	>10.6	1	
Groundwater depth	3.92-11.5	1	0.08
	11.51-19.07	2	
	19.08-26.65	2	
	26.66-34.22	3	
	34.23-41.80	3	
Rainfall	3390.03-3426.81	3	0.04
	3426.82-3463.59	3	
	3463.6-3500.37	2	
	3500.58-3537.14	2	
	3537.15-3575.92	1	
Geology	Gabbro	1	0.09
	Grey Fine Sand (Active Beach Ridge)	1	
	Sand (Active Channel)	1	
	Dolerite	2	
	Norite	2	
	Granite Gneiss	3	
	Granitoid	3	
	Laterite	3	
Elevation	<29	3	0.03
	30-67	2	
	>68	1	
Geomorphology	Active Quarry	1	0.02
	Anthropogenic Terrain	1	
	Back Swamp	1	
	Beach	1	
	Beach Ridge	1	
	Channel Bar	1	
	Channel Island	1	
	Older Coastal Plain	1	
	Younger Coastal Plain	1	
	Creek Network	1	
	Embankment	1	
	Estuarine Island	1	
	Active Flood plain	1	
	Older Flood plain	1	
	Lateral Bar	1	
	Mangrove swamp	1	
	Plateau Top	1	
	Point Bar	1	
	Point Bar	1	
	Rolling Plain	1	
	Spit	1	
	Swale	1	
	Tidal Flat	1	
	Valley	1	

	Valley Fill	1	
	Waterbody - Others	1	
	Waterbody - Pond	1	
	Waterbody - River	1	
	Abandoned Quarry	2	
	Residual Hill	2	
	Residual Mound	2	
	Scarp	2	
	Upland (Lateritic)	2	
	Pediment	3	
	Pedi plain	3	
LULC	Plain (Lateritic)	3	0.14
	Beach/Sandy	1	
	Built-up	1	
	Cropland	1	
	Vegetation/Plantation	1	
	Waterbody	1	
	Open land	3	
Proximity from Settlement	<200	1	0.16
	200-400	2	
	400-600	3	
	>600	3	
Soil depth	Very deep	3	0.07
	Deep	3	
	Moderate deep	2	
	Moderate shallow	1	
	River	1	
Proximity from Road Network	<200	1	11
	200-400	2	
	400-600	3	
	600-800	3	
	>800	3	
Proximity from Surface Water	<200	1	0.20
	200-400	2	
	400-600	2	
	600-800	3	
	>800	3	

Table.no. 5 Weightage and Ranking of Factors

importance to factors like rainfall, elevation, and geomorphology. These findings underscore the significance of strategic waste management in protecting the environment, public health, and efficient waste collection, all in alignment with the goals of the Mangaluru Smart City program. The study found that the current solid waste dump site near Pacchanadi is located within the 200-meter proximity zone of the settlement area, violating CPCB guidelines. As a result, it is imperative to identify a new dump site. Proposed suitable dump sites include

Delantabettu, Kullar (Kuthethur), Permude, Hosarpalla (Gurupura), Shakthinagara, Permanki, Saripalla, Neerumarga, and Kotipadavu (Fig no. 7).

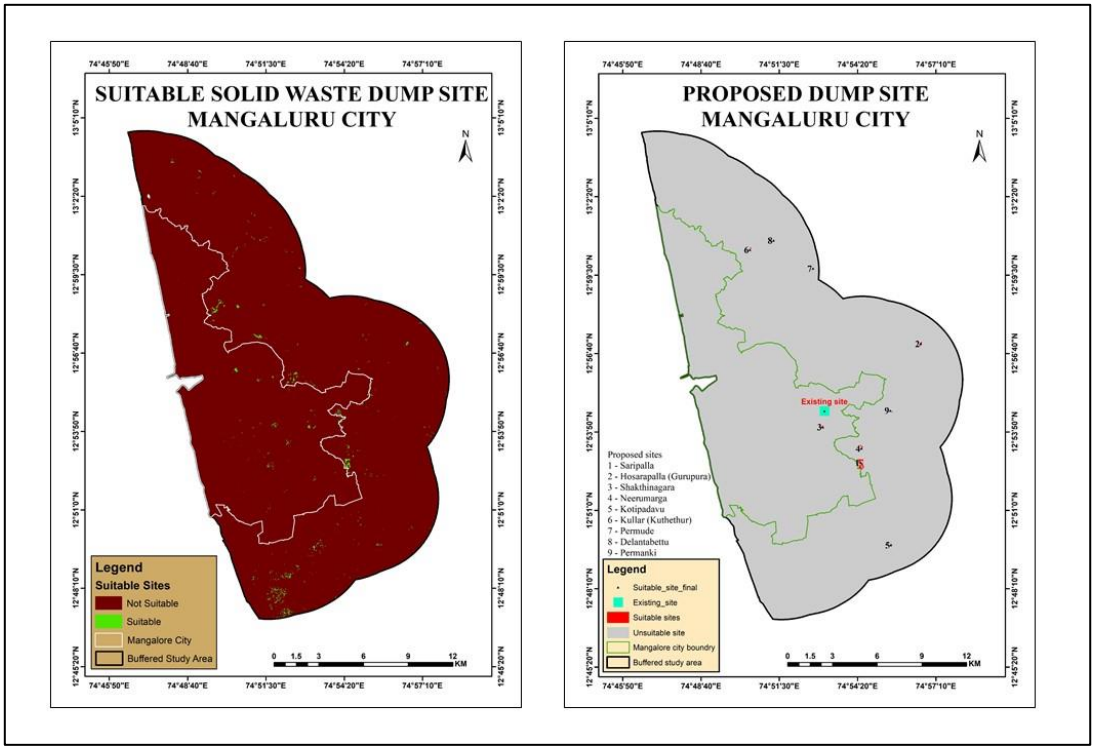

Fig. no. 7 Suitable and proposed dump site of Mangaluru city

SL. NO.	LOCATION	AREA (acres)
1	Saripalla	29.4
2	Hosarpalla (Gurupura)	5.9
3	Shakthinagara	5.5
4	Neerumarga	4.0
5	Kotipadavu	2.8
6	Kullar (Kuthethur)	2.3
7	Permude	1.6
8	Delantabettu	1.4
9	Permanki	1.0

Table no. 6 Suitable dump sites with its area coverage

CHAPTER 7: SUMMARY AND CONCLUSION

The final chapter provides a conclusion to the site suitability analysis for solid waste disposal in Mangaluru City using geospatial technologies and the Analytic Hierarchy Process (AHP). It successfully identified suitable waste disposal locations by considering various factors, promoting efficient waste management, and minimizing environmental impacts. These findings will aid local authorities and stakeholders in establishing organized waste disposal

facilities, enhancing public health and safety. However, the study acknowledges limitations and suggests continuous monitoring and updates to adapt to changing urban dynamics. This approach can serve as a model for other cities facing similar waste management challenges, contributing to a cleaner and more sustainable urban environment.

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